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## Description

Method for adjusting ~~the~~ tilting and the level of optical signals

Background of The Invention

Optical signals are transmitted via optical conductors. They are frequently amplified by using fiber amplifiers. These use either specially doped lengths of fiber, or utilize nonlinear effects on normal transmission fibers, as in the case of the Raman fiber amplifier described in ntz, volume 43, (1990), issue 1, pages 8 to 13.

In the case of many transmission devices, use is also made of attenuators with the aid of which required level values, <sup>(e.g.)</sup> ~~for example~~ the input levels of amplifiers, are adjusted, as is described, for example, in IEEE PHOTONICS TECHNOLOGY LETTERS, Vol. 6, No. 4, April 1994, pages 509 to 512.

Modern transmission systems use a plurality of signals with the aid of the wavelength division multiplex method, (WDM) in which a plurality of transmission channels are combined in each case to form a transmission band <sup>that</sup> ~~which~~ is amplified in common. The Raman effect produces an influence between the transmission bands, <sup>where</sup> ~~in the case of which~~ the levels of the individual signals (channels) are <sup>affected</sup> ~~differently~~ affected, which is denoted as tilting and to date has mostly been compensated by nonlinear amplifiers and filters. The fundamentals of the stimulated Raman scattering are described in Nonlinear Fiber Optics, Second Edition, Govind P. Agrawal, Academic Press, Chapter 8.

European Patent Application EP 0 139 081 A2 describes an optical communication system in which the transmitted optical signal is amplified on the basis of the stimulated Raman effect by a plurality of pump signals of different wavelengths. The different

pump signals are selected such that the gain characteristic and the signal levels run as ideally as possible.

European Patent Application EP 0 734 105 A2  
5 discloses a fiber amplifier which is used by means of a pump signal and a mirror for the purpose of compensating the dispersion. Figure 47 shows the tilting of the signal levels (slope gain) as a function of the pump power.

10 GB 2 294 170 A describes an arrangement for amplifying which monitors the number of active channels and also keeps the level at a preselected value in the event of absence of individual channels.

Patent Abstracts of Japan publication number  
15 59065828/application number 57176312 describes an amplifier for a continuous optical signal (constant wave). The light from a signal source 11 of shorter waves is converted to the wavelength of the auxiliary light source of longest waves with the aid of the  
20 auxiliary light sources 13 to 20, tuned to the Stokes wavelength, on the basis of the stimulated Raman effect.

None of these references provides satisfactory adjustment or compensation of the tilting, in  
25 particular in the case of WDM systems with a plurality of transmission bands.

Particularly in the case of WDM systems in which a plurality of groups of signals are transmitted, the stimulated Raman scattering, (SRS), is to amplify the  
30 signals transmitted in "longwave" channels at the expense of the signals transmitted in "shortwave" channels; in other words, energy is extracted from the shortwave "blue" channels, which are more strongly damped with decreasing wavelength (increasing  
35 frequency), while this benefits the longer wave "red" channels. The larger the wavelength, the more the

corresponding transmission channels profit. A similar statement holds for the spectral components of signals with high bit rates.

The influence of the SRS effect is illustrated in Figures 1 and 2. The left-hand diagram <sup>of Figure 1</sup> shows a constant reception level, independent of wavelength, of the blue transmission band (wavelength region)  $\lambda_B$ . The right-hand diagram illustrates the reception level when simultaneous use is made of a further "red" wavelength region for optical signal transmission. The smaller the wavelength of the blue transmission band, the stronger the attenuation.

The level relationships for the "red" transmission band  $\lambda_R$  are illustrated in Figure 2. The left-hand diagram <sup>in Figure 2</sup> again shows the linear level characteristic for <sup>the</sup> case where signals are transmitted only in this transmission band. If, in addition, there is transmission in the "blue" wavelength region, the level is raised higher with increasing wavelength. This depends only slightly on whether the signals in the transmission bands are transmitted in the same or opposite directions (co-propagating waves - counter-propagating waves). The change in the levels, illustrated in the right-hand diagrams of Figures 1 and 2, as a function of the wavelength, which corresponds to a pivoting about a common fulcrum, is denoted as tilting.

In today's typical transmissions with two times eight channels, the effect described gives rise to additional attenuations or amplifications in a transmission section (approximately 40-80 km) of between 0.4 to 0.7 dB. In the case of transmission links with up to 10 or more transmission sections and a corresponding number of repeaters, these changes in level add up correspondingly. If one of the transmission bands is absent, there is also a very quick change in the level of the signal in the intact

transmission band. The automatic gain control at the receiving end can usually not compensate these

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level fluctuations quickly enough, the result being error bursts in the millisecond region. A quick restitution of the previous level is required in this case.

5 For many applications, it is ~~to be~~ possible for the level and the tilting of signal bands to be adjusted frequently independently of one another.

*Summary of the Invention*  
It is therefore ~~the~~ object of the invention to specify a method and an arrangement for adjusting the  
10 tilting for broadband optical signals. The method is also intended to be used for simultaneous level adjustment.

A further object ~~therefore~~ consists in designing the method for rapid stabilization of the  
15 tilting and of the signal level of an intact transmission band in the event of absence of another transmission band and to specify a suitable arrangement.

A method which achieves the main object is  
20 specified in patent claim 1. A solution in the case of the transmission of a plurality of signal bands is specified in the independent patent claim 4. Independent patent claims 15 and 16 respectively describe a suitable arrangement

25 Advantageous developments of the invention are specified in the dependent claims.

<sup>Adv</sup>  
The ~~the~~ advantage of the method according to the invention is that the tilting and the signal level can be adjusted largely independently of one another in  
30 conjunction with the use of two pump signals. The signal <sup>(e.g.)</sup> ~~for example~~ a wavelength multiplex signal, can be both amplified and attenuated by the method. Moreover, the tilting can be changed in relatively wide ranges, thus producing a desired equalization of the  
35 signal. Pump lasers feed in pump signals with wavelengths above and/or below the

transmission band. These pump signals either extract energy from the signal or lead energy to it. Consequently, the signal is amplified or damped by varying the pump energy, <sup>with</sup> tilting simultaneously occurring.

The suitable selection of the pump laser wavelengths can be used to control gain/attenuation and tilting in wide ranges. The required tilting can also already be achieved by means of a suitable pump signal of greater wavelength.

It is advantageous if the pump energy is fed in at the receiving end, since this leads to a more favorable signal-to-noise ratio. The tilting is independent of the spacing of the wavelength of the pump laser from the (mean) wavelength of the signal. The arrangement can preferably also be carried out only as an attenuator. The degree of tilting can be determined as a function of the attenuation by the selection of the pump wavelength. Such an "optical attenuator" can also be used to control the level of the optical signal at the receiving end. In a particularly simple attenuator tailored to the respective application, only one laser is used, the result being to produce a desired functional relationship between attenuation and tilting.

In the absence of one transmission band, the level remains virtually constant in the undisturbed transmission band whenever the pump laser is used either as an energy supplier or as an energy absorber which compensates for the action of the absent transmission band. Since the change in power of the pump laser <sup>that</sup> ~~which~~ is required to compensate the absent transmission band is known, its absent corresponding power is very quickly changed so that as few transmission errors as possible occur. An exact readjustment is not required in general, but can additionally be provided.

In general, a more favorable signal-to-noise ratio results when the pump laser is used at the receiving end. Here, the controller can also intervene in the receiving amplifier, if appropriate, in order to achieve an optimum level characteristic by controlling its transmission response.

In order <sup>to</sup> simultaneously ~~to~~ use the level to compensate the tilting of the undisturbed transmission band, it is advantageous if the frequency of a pump laser which has been turned off in the case of undisturbed operation corresponds approximately to the center frequency of the absent transmission band.

For the purpose of optimum compensation of the absent transmission band, it is ~~expedient~~ <sup>advantageous</sup> to use a plurality of pump lasers having different wavelengths below and/or above the transmission bands. Optimum compensation is already possible with two pump signals of different wavelengths. It is also favorable <sup>to</sup> though often not possible to realize <sup>to</sup> to use a pump laser whose frequency is between the two wavelength regions, since the transmission bands are then treated equally with preference to damping and gain.

Exemplary embodiments of the invention are explained ~~in~~ <sup>A</sup> in more detail with the aid of figures, in which:

Figure 3 shows a block diagram of the level adjustment of an optical signal <sub>i</sub>

Figure 4 shows the level characteristic of an optical signal as a function of two pump signals <sub>i</sub> and

Figure 5 shows a device for level control <sub>i</sub>

Figure 6 shows a transmission section provided with a pump laser,

Figure 7 shows a transmission section with a pump laser inserted at the receiving end,

5 Figure 8 shows a transmission section with a pump laser inserted at the transmitting end and a pump laser inserted at the receiving end,

Figure 9 shows a transmission section with two pump lasers ~~inserted at the receiving end, in a~~ preferred exemplary embodiment, and

10 Figure 10 shows two pump lasers, inserted at the receiving end, for bidirectional operation.

<sup>Description of The Preferred Embodiments</sup>  
Figure 3 shows a transmission section with a transmitting device <sup>(e.g. for example</sup> a laser or an amplifier <sup>that</sup> which feeds an optical signal  $OS_s$  with the relatively large wavelength region  $\lambda_s$  into an optical conductor LW, and a receiving device R, which likewise has an amplifier. The optical signal can, for example be a digital multiplex signal with a relatively large bandwidth, or a wavelength multiplex signal. The optical signal (received signal)  $OS_E$  damped by the transmission link is fed to the receiving device R.

Arranged at the receiving end are two pump lasers PL1 and PL2 <sup>that</sup> which feed into the optical conductor <sup>LW</sup> via a coupler K a pump signal PS1 <sup>having</sup> with a wavelength  $\lambda_B$  <sup>that</sup> which is below the smallest wavelength  $\lambda_{MI}$  of the optical signal, and a pump signal PS2 with a wavelength  $\lambda_R$  which is above the largest wavelength  $\lambda_{MA}$  of the optical signal <sup>see e.g.</sup> (Figure 2). The pump signal PS2 attenuates the optical signal  $OS_E$ . The higher the power of the pump signal, the weaker the optical signal becomes. This attenuation increases with the difference in the wavelength of the optical signal from the wavelength of the pump laser. The pump signal PS1 increases the signal level again, but the tilting takes place in the same direction of rotation. However, since the spacing from the frequency band  $\lambda_s$  or



its mean or smallest wavelength  $\lambda_{MI}$  is not equal to the spacing of the wavelength  $\lambda_R$  of the second pump signal, a different relationship results between the gain and tilting. Thus, different tiltings can be implemented for adjustable attenuation values or gain values.

If an "attenuator" dependent on wavelength is to be implemented, the action of the pump laser with a "red" wavelength (greater than the maximum wavelength  $\lambda_{MA}$ ) must predominate. If, by contrast, an amplifier is to be implemented, the action of the "blue" pump laser with a "blue" wavelength (smaller than the minimum wavelength  $\lambda_{MI}$ ) must predominate.

In a simplified embodiment of an "attenuator", in the case of which, however, it is no longer possible for the tilting and level to be adjusted independently, only a "red" pump laser is used.

Moreover, amplifiers can also be implemented which have at least two "blue" pump lasers and permit different tiltings in conjunction with the same gains. Likewise, attenuators can be implemented which have at least two "red" pump lasers and which permit different tiltings in conjunction with the same attenuation values.

The action of two pump lasers is shown in Figure 4. The upper level characteristic drawn with a broken line (P - level,  $\lambda$  - wavelength) of the optical received signal  $OS_{E1}$  initially has a relatively large level at small wavelengths, and a small level at large wavelengths. This characteristic, which overcompensates the Raman effect active on the transmission link is achieved by means of filters or amplifiers at the transmitting end or receiving end.

However, as soon as the pump laser PL2 is switched on, the received signal  $OS_{E2}$  is attenuated, the

shorter wave (higher frequency) signals being more strongly attenuated. Once the pump laser PL becomes active, the level is raised again, the tilting of the received signal  $OS_E$  is, however, amplified once more, and a linear level characteristic is achieved.

Since the spacings of the wavelengths of the pump lasers relative to the received signal are different, the tilting and level can be adjusted independently of one another in specific regions. If the wavelengths of the two pump lasers are greater than the maximum wavelength of the received signal, the attenuation can be adjusted in a larger region and independently of the tilting. *Similarly, this principle also applies to blue pump laser in a corresponding manner*

Figure 5 shows a pump laser PL as part of a control circuit arranged at the receiving end. *according to another embodiment* A part of the optical received signal  $OS_E$  is outcoupled as measuring signal via a measuring coupler K2 and fed to a controller ST which keeps the amplitude of the optical received signal constant by controlling the pump laser, which feeds its pump signal into the optical conductor via a coupler K1 (here, a coupler is understood to be any device *that* which permits a signal to be fed in). The controller *ST* can additionally intervene in the receiving *device R* and control the pump laser and the gain or gain tilting in accordance with a prescribed scheme. Instead of a controller, it is also possible to use a control circuit or the combination of an open-loop controller and a closed-loop controller.

Figure 6 shows a link section with transmitting device *(e.g.)* ~~for example~~ an amplifier at the transmitting end which feeds an optical signal  $OS$  into an optical conductor  $LW$ , an optical conductor  $LW$  and a receiving device  $R$ . The optical signal comprises, for example, two times eight channels which are emitted in a blue transmission band  $\lambda_B$  (1535 to 1547 nm) and a red transmission band  $\lambda_R$  (1550

A first pump laser PLL is <sup>10</sup> provided  
 to 1562 nm). <sup>10</sup> Provided at the transmitting end  $f_n$  or also  
 at the start of any desired link section between the  
 illustrated amplifiers) + is a first pump laser PLL  
 which <sup>that</sup> sends into the fiber of the optical conductor LW  
 5 a pump signal PS of constant wavelength  $\lambda_{L1}$  via an  
 optical coupler K2 (a coupler is always understood as  
 any device which permits a signal to be fed in). This  
 can be both a longwave "red" pump laser whose  
 wavelength is above the wavelength of the "red"  
 10 transmission band at approximately 1600 (up to  
 approximately 1630 nm), and a shortwave "blue" pump  
 laser with a wavelength at 1480 nm (up to approximately  
 1440 nm).

15 The pump lasers can be used (together with  
 suitable filters or amplifiers) both in undisturbed  
 operation for the purpose of compensating the Raman  
 effect or other nonlinearities, and in the event of  
 absence of a transmission band for the purpose of  
 compensating the change in level caused by the Raman  
 20 effect.

Assuming that the pump laser is active during  
 undisturbed operation, its power is (as a rule), lower  
 than the signal power. If a longwave pump laser is used  
 and if the red band is absent, the pump power must be  
 25 increased in order to extract more energy from the blue  
 transmission band. If, by contrast, the blue band is  
 absent, the power of the pump laser must be lowered so  
 that less energy is extracted from the "red"  
 transmission band.

30 The relationships are exactly reversed in the  
 case of a shortwave "blue" pump laser. If the red band  
 is absent, the power must be lowered, since less energy  
 has already been extracted from the blue transmission  
 band. If, by contrast, the blue transmission band is  
 35 absent, the power of the pump laser must be increased  
 in order, as before, to supply the same energy to the  
 red transmission band.

In order to establish the absence of the transmission band, or else individual channels, a suitable controller ST must first~~y~~ separately measure the signal levels of both transmission bands. For this purpose, the transmitted signals are fed to measuring devices ME via a measuring coupler K1 and suitable optical filters FI1, FI2. The values of the measured signal levels, for example the aggregate level, are fed to a control device SE which readjusts the power of the pump oscillator in accordance with the change.

The pump laser, which only couples in pump power in the event of a disturbance, can also operate at the mean frequency of the absent transmission band in order to render optimum compensation possible.

Given the use of a suitable measuring device, the pump laser can also be used to correct the level and tilting of any desired signal.

In Figure 7, a pump laser PL2 with an associated coupler <sup>K4</sup>~~K3~~, and a controller ST with an associated coupler <sup>K4</sup>~~K3~~, are arranged at the receiving end. The arrangement at the receiving end is to be preferred because of the more favorable signal-to-noise ratio. The controller ST can, moreover, intervene in amplifier stages V and an attenuator D of the receiving part R and optimize the overall gain/attenuation and the tilting.

Illustrated in Figure 8 is a link section in which at the transmitting end ~~λ~~ (this can be any point between the transmitting device S and receiving device R) ~ a first pump laser PL1, and at the receiving end a second pump laser PL2 feed in pump signals of the same wavelength  $\lambda_{L1}$  via couplers K2 and K3, respectively. It is thereby possible to use weaker pump lasers. Owing to the laser at the transmitting end, <sup>(i.e., PL1)</sup> there is also a quicker reaction to the absent signal/transmission band. Likewise, pump lasers with

different wavelengths can be used in order to obtain a better compensation for the absent signal.

The illustration of details such as the controller and the measuring couplers has been dispensed with in this figure and in the further <sup>figures</sup> ones.

In Figure 9, pump signals PS2, PS3 of different wavelengths  $\lambda_{L2}$ ,  $\lambda_{L3}$  are fed in by <sup>respectively</sup> two pump lasers PL2, PL3, arranged at the receiving end, via a <sup>corresponding</sup> coupler K5. The powers of the lasers can be lower <sup>this arrangement</sup> thereby. Both the tilting and the change in level can be optimally corrected by a combination of a suitable red and a blue pump laser. In principle, it is also possible to achieve a better compensation by means of two red or two blue pump lasers with different pump frequencies.

Pump signals at the corresponding wavelengths can additionally be fed in at the transmitting end in a corresponding compensation unit KE. It is then also possible, for example, to fit the compensation unit <sup>KE</sup> at the transmitting end with an open-loop controller, and the pump lasers at the receiving end with a closed-loop controller.

Of course, it is also possible in principle to use more than two pump lasers. Likewise, the method can also be applied for more than two transmission bands.

Figure 10 shows a transmission section for bidirectional operation. The signals for different transmission directions are separated by separating filters W. Two pump lasers PL2 and PL3 (or else two in each case) feed in pump signals PS2 and PS3 at both ends of the transmission section, in order to achieve optimum compensation for each received signal, even in the event of absence of a signal.